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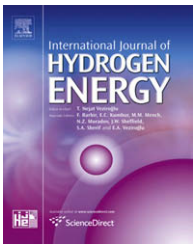

Hydrogen the fuel for 21st century

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ABSTRACT

Non-Conventional Energy Sources, such as solar and hydrogen energy will remain available for infinite period. One of the reasons of great worry for all of us is reducing sources of conventional energies. The rate of fossil fuel consumption is higher than the rate of the fossil fuel production by the nature. The results will be the scarcity of automobile fuel in the world which will create lot of problems in transport sector. The other aspect is pollution added by these sources in our environment which increases with more use of these sources, resulting in the poor quality of life on this planet. There is constant search of alternate fuel to solve energy shortage which can provide us energy without pollution.

Hence most frequently discussed source is hydrogen which when burnt in air produces a clean form of energy. In the last one decade hydrogen has attracted worldwide interest as a secondary energy carrier. This has generated comprehensive investigations on the technology involved and how to solve the problems of production, storage and transportation of hydrogen. The interest in hydrogen as energy of the future is due to it being a clean energy, most abundant element in the universe, the lightest fuel, richest in energy per unit mass and unlike electricity, it can be easily stored. Hydrogen gas is now considered to be the most promising fuel of the future. In future it will be used in various applications, e.g. it can generate Electricity, useful in cooking food, fuel for automobiles, hydrogen powered industries, Jet Planes, Hydrogen Village and for all our domestic energy requirements.

Hydrogen as a fuel has already found applications in experimental cars and all the major car companies are in competition to build a commercial car and most probably they may market hydrogen fuel automobiles in near future but at a higher cost compared to gasoline cars but it is expected that with time the cost of hydrogen run cars will decrease with time. Long lasting, light and clean metal hydride batteries are already commercial for lap top computers. Larger capacity batteries are being developed for electrical cars. Hydrogen is already being used as the fuel of choice for space programmes around the world. It will be used to power aerospace transports to build the international space station, as well as to provide electricity and portable water for its inhabitants. Present article deals with the storage and applications of hydrogen in the present energy scenario.

1. Introduction

Due to rising energy demand and reducing Conventional Energy Resources the use of "Renewable Energy" becomes important. The other aspect is Pollution added by conventional energy in our environment. The coming decade will see greater use of "Green Power" to ensure less dependence on "Fossil Fuels" and to prevent environmental degradation

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Table 1 – Heat of combustion of various fuels.

Fuel	Energy (Kcal/g)
Hydrogen	34.0
Petroleum	10.3—8.4
Paraffin	10.3—9.8
Graphite (Coal)	7.8
Castor oil	9.4
Wood	4.2

>which will result in improved quality of life of people. Energy is an important aspect in the development of any nation. In view of the rising energy demand and reducing sources of conventional energy; Energy Conservation, Management and Applications of the Non-Conventional Energy Sources becomes imperative. The other aspect is pollution added by these sources in our environment. The more we use these sources the more is pollution added to our environment, the poorer is our quality of life on this earth.

2. Reasons for interest in HYDROGEN

- Clean Energy → without Pollution.
- Most abundant element in the universe.

Table 2 – Hydrogen concentration in different systems.

System	Density (g/cm^3)	H atoms per unit volume ($\times 10^{22}/cm^3$)	Weight % H hydrogen
Liquid H_2	0.07	4.2	100.0
Gas	0.008	0.5	100.0
H_2O (Liquid)	1.0	6.7	11.2
H_2O (Liquid)	0.6	6.7	18.0
$FeTiH_2$	5.6	6.2	1.9
$LaNi_5h_6$	6.5	7.0	1.4
VH_2	5.0	11.2	2.1
MgH_2	1.4	6.7	7.6

- Lightest fuel
- Richest in energy per unit mass.
- Can be stored easily.
- Can be produced by water.
- Direct conversion into: thermal, mechanical and electrical energy (Table 1).

Hydrogen has established it as a viable source of energy and world over scientists are involved in making it commercially available source of energy because of its environmentally friendly nature.

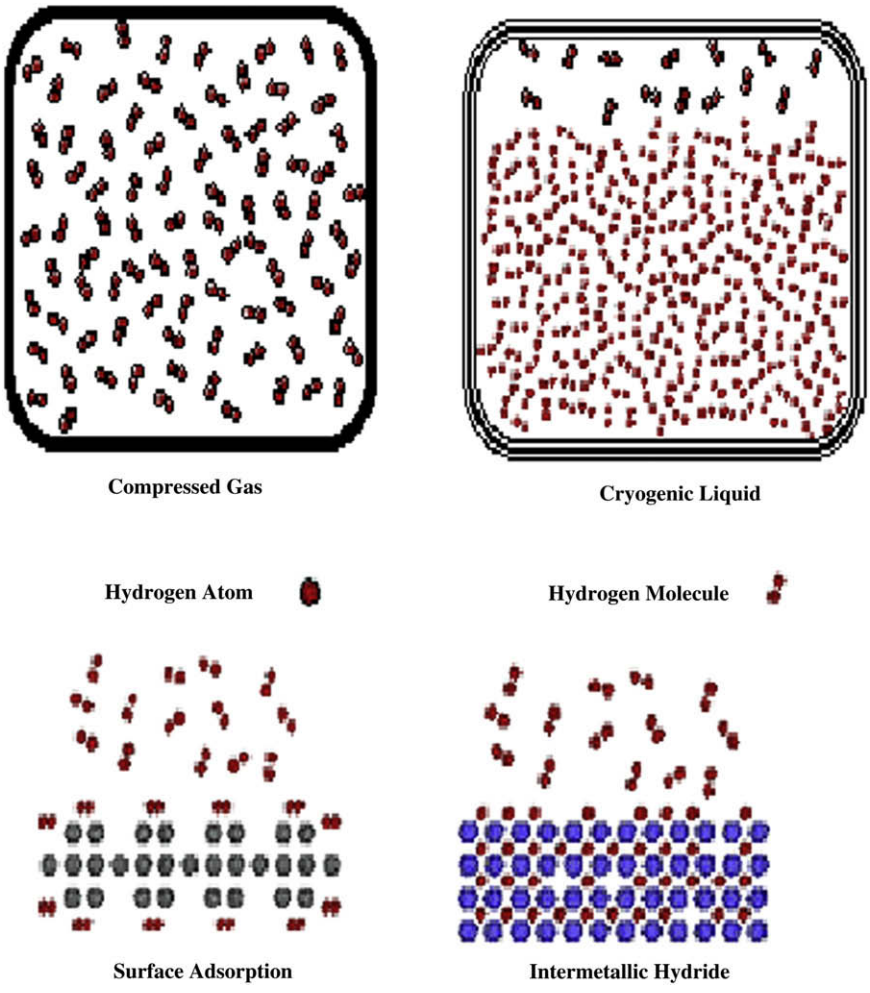

Fig. 1 – Hydrogen in gas, liquid and in metal hydrides.

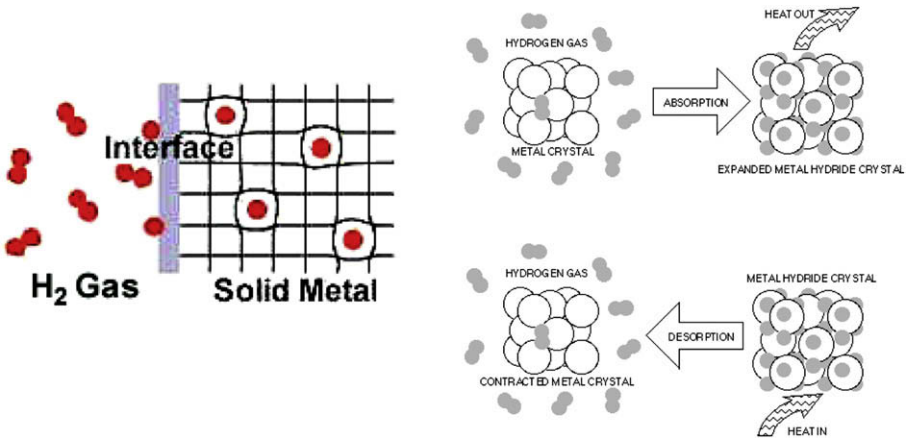

Fig. 2 – Simplified model of metal–hydrogen interaction.

3. The hydrogen cycle: hydrogen energy system for sustainable future

In this cycle the initial water is dissociated using any primary source of energy into Hydrogen and Oxygen, they than combined in a fuel cell to generate electricity. Power so generated can be of any application and in the end water comes out as an emission product. Therefore, it will be better for the world population to switch over to hydrogen for its energy requirements.

Why hydrogen?
Reasons why India should switch to a Hydrogen Energy Economy:

1. Investing in hydrogen development would keep the INDIA in step with global competition
2. Relying on the Middle East for energy weakens national strength. The *INDIA* could be energy self-sufficient with hydrogen
3. Converting to a hydrogen-based economy would create thousands of permanent scientific and industrial jobs.
4. Someday, fossil fuels will run dry. Hydrogen is renewable and, therefore, unlimited. Solving energy supply problems today will ensure our nation's stability tomorrow.
5. Pollution from cars and airplanes has created smog clouds across many cities of the country. Hydrogen emits no toxins.
6. Huge oil spills are becoming common, killing countless water creatures. The effects on our food chain are unknown. If hydrogen were spilled, it would evaporate immediately. The only by-product of hydrogen fuel is water.
7. Mass consumption of oil requires continued drilling into pristine wilderness areas, wreaking havoc on some of the world's greatest ecosystems. Hydrogen production leaves no environmental scars.
8. Indian trade balance sheets show that oil imports drain lot of foreign currency from the Indian economy every week.

4. Methods for hydrogen storage

Fig. 1 shows three types of hydrogen storage technique.

- Gas ► Needs heavy vessels stored at high pressure not economical.

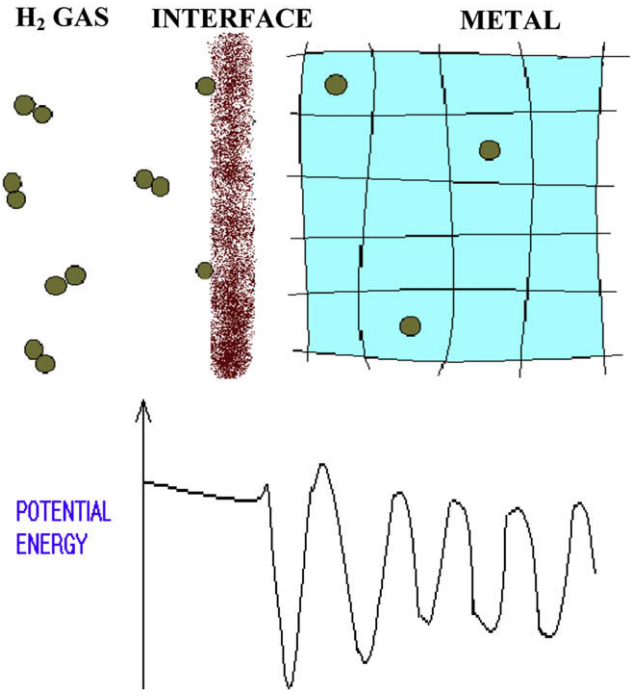

Fig. 3 – Dissociation of molecular hydrogen at an interface and the solution of hydrogen atoms in the bulk.

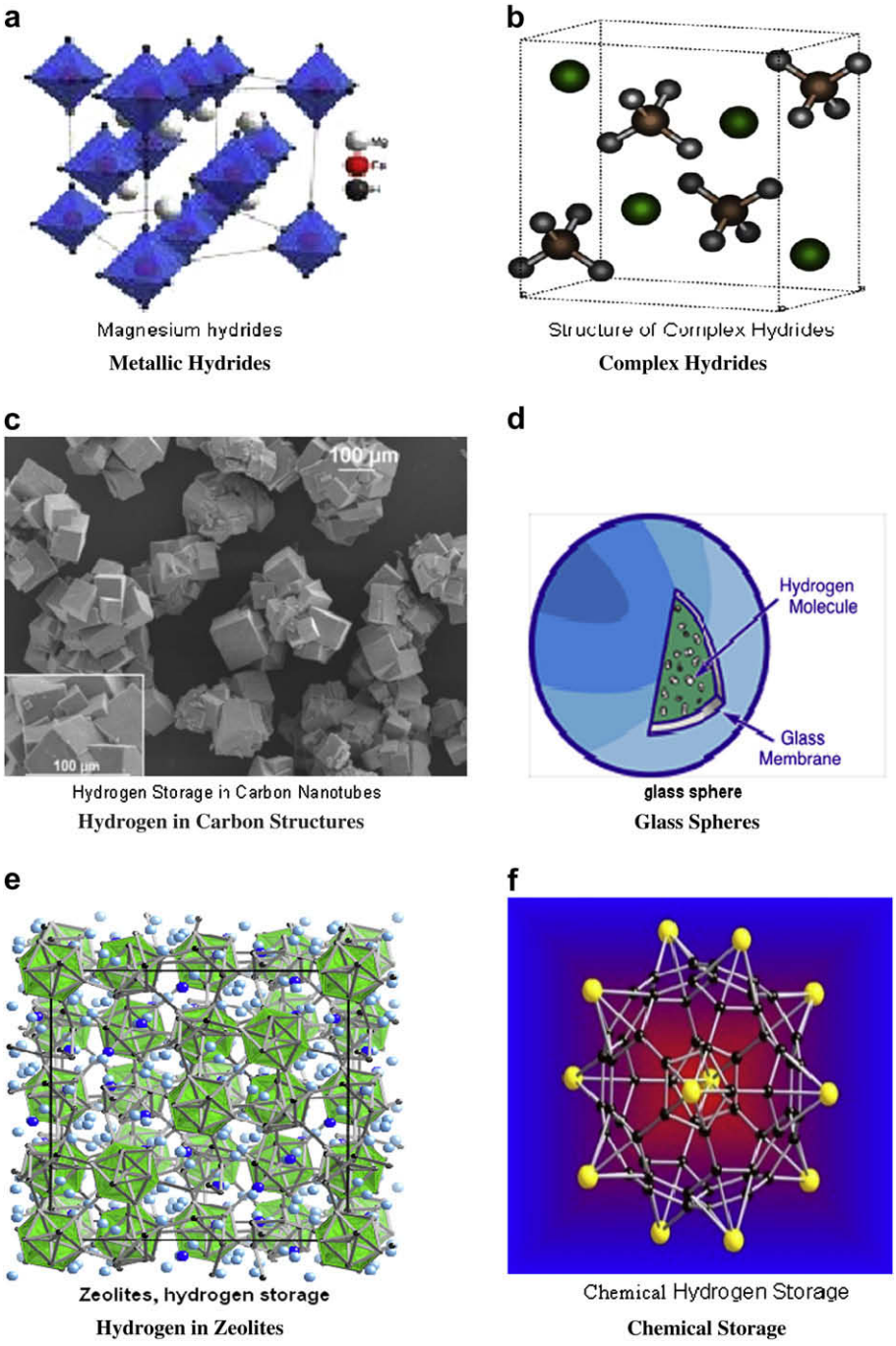

Fig. 4 – Various types of hydrogen storage devices (a)–(f).

- Liquid ► Liquefaction needs energy highly volatile extremely cold (boils at 20 k).
- Metal Hydrides ► Store H_2 compactly & safely at ambient temperatures

4.1. *Hydrogen can be stored in different forms in tanks or materials*

Hydrogen can be stored on the surfaces of solids by adsorption or within solids by absorption.

a. Adsorption: Hydrogen attaches to the surface of a material either as hydrogen molecule (H_2)or hydrogen atoms (H).
b. Absorption: Hydrogen molecules dissociate into hydrogen atoms which are incorporated into the solid lattice framework- this method may make it possible to store large quantities of hydrogen in small volumes at low pressure and temperatures close to room temperature.
c. Metal Hydride: Finally hydrogen can be strongly bound within molecular structure, as chemical compounds containing hydrogen atoms.

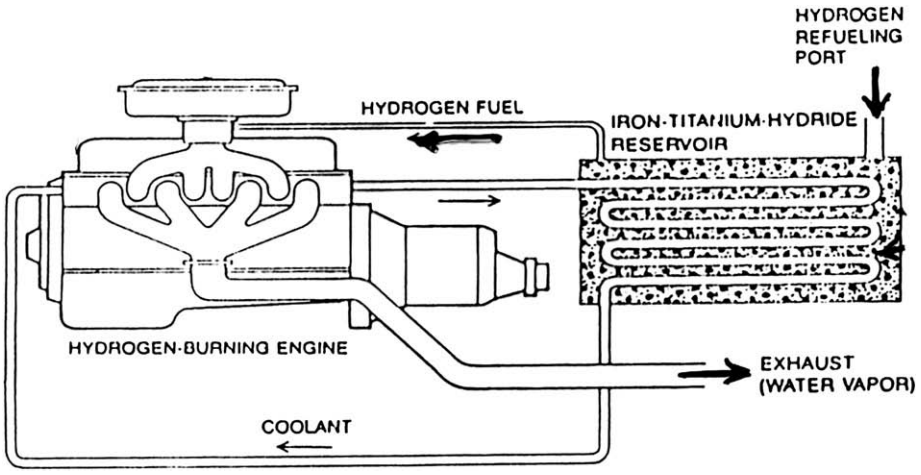

Fig. 5 – Metal hydride and internal combustion engine.

4.2. *Gaseous hydrogen storage*

The most commonly used and simplest method is to store hydrogen in its natural form. Storage of gaseous hydrogen is primarily limited by volume considerations as a result of hydrogen's low density and even at high pressures, very large volumes are required resulting into high material costs. Hydrogen is compressed to between 200 and 280 bars in cylindrical tank of up to 50 l. These tank may be made from carbon or graphite compounds. This type of storage involves the energy of compression/about 4 kcal/mol H_2 and suffers from a heavy weight.

4.3. *Liquid hydrogen storage*

Hydrogen can be stored as a liquid at 20 k (−253 °C) in super insulated tanks. This process is both long and energy intensive. Up to 40% of the energy content in the hydrogen can be lost. The advantage of liquid hydrogen is its high energy. Mass ratio, three times of gasoline, it is the most energy dense fuel. Liquid hydrogen must be stored in cryogenic tank which is a well established technique.

4.4. *Metal hydrides*

Metal hydrides are the materials which are capable of functioning like a ''sponge'' for absorbing & ''squeezing out'' hydrogen, the mechanical action being provided by small changes in temperature and pressure. The use of metal hydride for the storage of hydrogen as a fuel is an important development. The method uses an Intermetallic phase of various metals that can absorb and hold large amounts of hydrogen by chemical bonding. Metal hydrides are prepared by reaction between a metal and alloy phase and hydrogen.

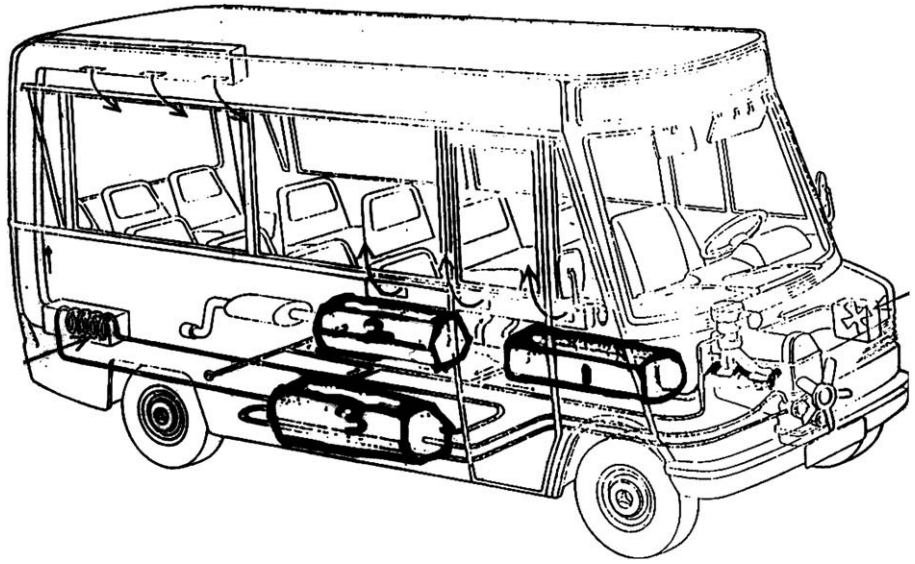

Fig. 6 – Hydrogen powered bus by Dailmer Benz, Germany.

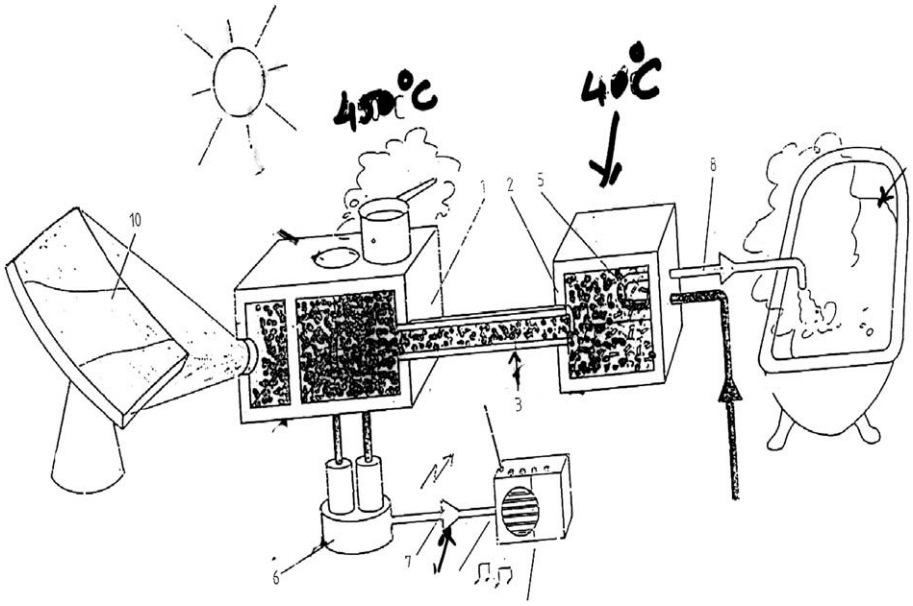

Fig. 7 – Day operation.

When exposed to hydrogen at certain pressures and temperature, these phases absorb large quantities of hydrogen gas and form corresponding metal hydride. Hydrogen in metal hydride presently is a safer fuel than the compressed gas or liquid hydrogen. Several metal hydrides are available commercially representing a good solution for hydrogen storage where the weight factor is not a problem (Table 2).

5. Hydrogen absorption mechanism

$$M + (x/2)H_2 \leftrightarrow MH_x + \text{Heat}$$

The metal-hydrogen system consists of a metallic material, hydrogen gas, and an interface region between them.

Hydrogen gas adsorbs onto the interface region. At the interface, the molecule is dissociated into individual hydrogen atoms that are able to absorb or dissolve into the metal phase. The random dissolution of hydrogen atoms in the metal phase is known as the α-phase. Within the metallic phase, the hydrogen atoms can start to arrange themselves in a specific configuration with the metal atoms, forming the metal hydride phase, called the β-phase. Where and how the β-phase is nucleated and grows is a characteristic of the material. Fig. 2 shows the expansion of lattice due to hydrogen absorption and contraction on desorption.

The potential energy indicates atom left to right, a shallow minimum for physisorbed hydrogen, a deep minimum for chemisorbed dissociated hydrogen, a rather deep minimum for near surface hydrogen and periodic minima for hydrogen dissolved on Interstitial site for the host metal separated from

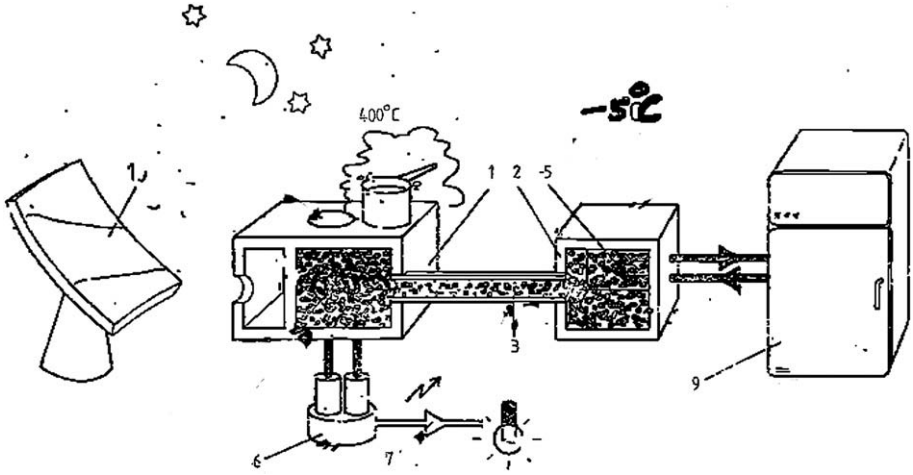

Fig. 8 – Night operation.

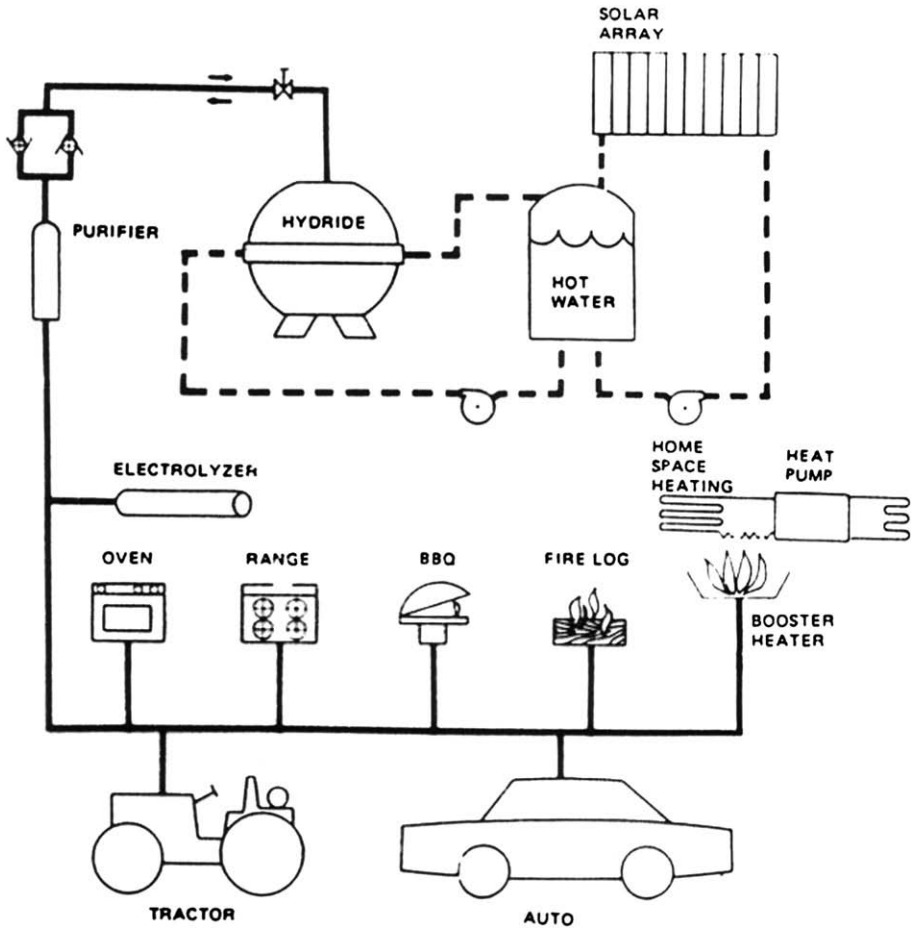

Fig. 9 – Metal hydride for hydrogen village for 30 homes.

each other by diffusion barriers as shown in Fig. 3. Fig. 4 shows various types of hydrogen storage materials, e.g. metallic hydrides (FeTi, $LaNi_5$,) complex hydrides (Li, K and Na alanates), hydrogen in carbon structure (carbon nanotubes, carbon suit), hydrogen in glass spheres, zeolites and various types of chemical storage medias (boro hydrides, ammonia, methyl alcohol).

6. Applications of metal hydrides

6.1. *Metal hydride used for internal combustion engine*

Hydrogen gas from metal hydrides has been extensively used for various stationary and mobile applications. One such application was used to run an internal combustion engine shown in Fig. 5, where the heat of decomposition for the release of hydrogen from Metal Hydride is supplied by the Engine. When hydride bed is exhausted it can be recharge by Hydrogen.

Fig. 6 shows a Dailmer Benz metal hydride bus. This bus is consists of three hydride beds:

1. High Temperature Mg Hydride Bed,
2. Low temperature FeTi Hydride Bed,
3. Liquid Heat Exchanger to provide AC for Bus

6.2. *Metal hydrides used for domestic applications*

Metal hydrides have been used for domestic applications, e.g cooking, heating, cooling and power generation both during day and night time. Day operation of a metal hydride station has been successively demonstrated by a Solar Power Station designed by Bomin Solar Germany and is shown in Fig. 7.

In such system Solar Collector is used during day time for heating hydride bed which is an active Mg hydride bed giving a temperature of 400 °C for cooking purpose. Another unit of low temperature is used for cooling purpose. Hydrogen released from hydride bed combines with hydrogen in a fuel cell generates electricity which is stored in a battery for night operation as shown in Fig. 8.

During day time the electrical energy stored in batteries is used during night time to heat hydride bed to run a hot plate, a refrigerator and for lighting purpose.

6.3. *Hydrogen village*

Fig. 9 schematically shows Solar Arrays to heat water which than supply heat to hydride bed to release hydrogen. Hydrogen so released can be used for various Domestic Applications of Hydrogen Energy as demonstrated by Billing Energy Corp. Provo, Utah, USA.

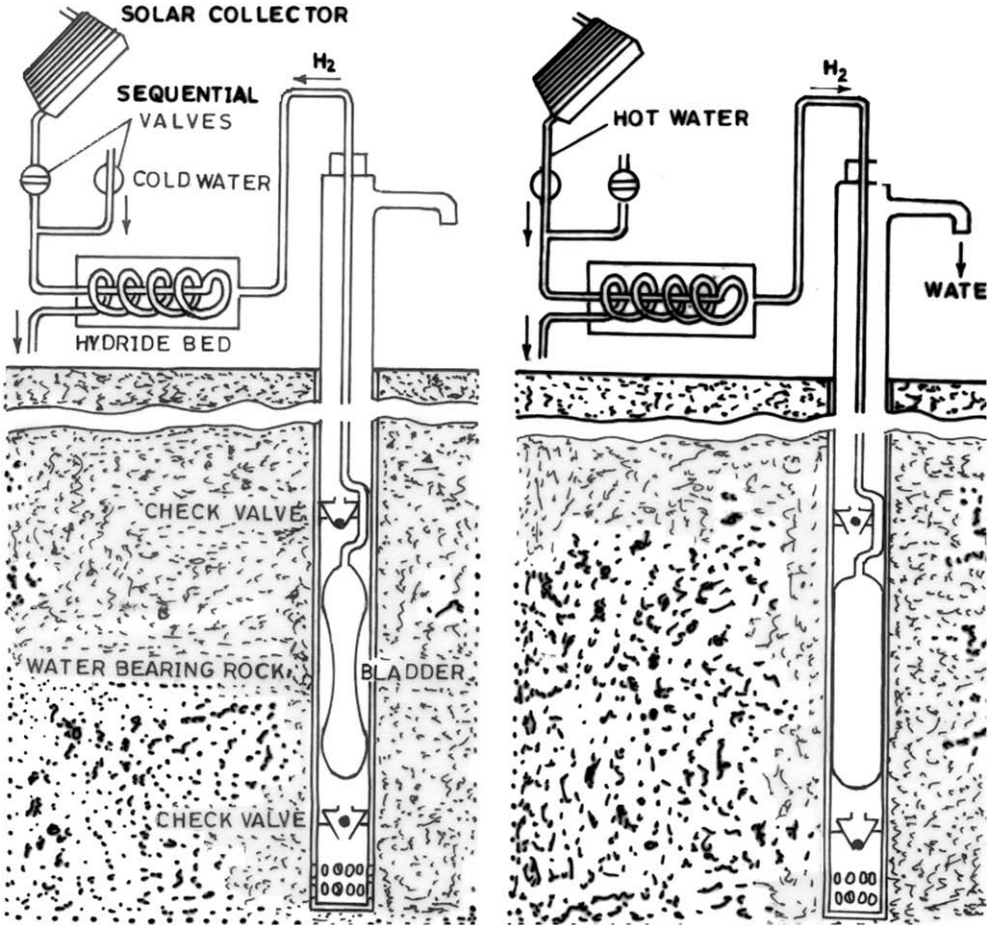

Fig. 10 – Solar powered hydrogen run water pump.

6.4. *Solar powered hydrogen run water pump*

One of the applications of hydrogen run rubber bellow is for: Running a Water Pump. These water pumps will find application in lifting water from wells in villages in India. The villages which are not connected to electric power will find its immediate application.

6.4.1. *Inflation of rubber bellow*

The above Fig. 10 gives the working principal of solar powered hydrogen run water pump. In which hot water produced by solar heat releases hydrogen to inflate a rubber bellow.

6.4.2. *Deflation of rubber bellow*

Cold water form the well used to cool the hydride bed and the hydrogen goes back into the hydride bed, deflating the rubber bellow. Inflation and deflation of Rubber Bellow gives pumping action to pumps out water from the well. Such type of water pump has been developed by Sandia Laboratory USA and the laboratory model is working in our Centre.

6.5. *Fuel cell*

Fig. 11 gives schematically the working of a Fuel Cell which operates like a battery: In fuel cell hydrogen at anode while passing through a polymer membrane gives an electron and at cathode reacts with oxygen to form water. The fuel cell does not run down or require charging. But it produces electricity and heat as long as H_2 is supplied.

6.6. *Important applications of fuel cells*

NEW Advances in Hydrogen Energy. One km per gram of Hydrogen Bike. HYSUN 3000 European Bike, 3000 kms on 2 kgs of H_2, max. speed 80 km/h, weight 120 kgs. (Fig. 12).

The ''Fuel Cell'' bike is almost silent. To introduce an artificial engine noise for urban areas and switched off in the countryside to allow peaceful ride (Fig. 13).

a. Production capability of hydrogen fueling station is 26,000 l (at 350 bar) per yr. Cars can be fueled at the rate of 20 l/min.
b. Fuel cell powered ship to be in the market by Dec 2009.
c. Hydrogen car is weighing about 2750 pounds, the eco-Voyager doesn't have a problem performing like the cars we know and love, either. 0–60 is dispatched in 8.8 s, and Chrysler's claiming a 12.9 s quarter mile, which we find astounding to the point of disbelief.
d. This is for Under Ground Use, VEHICLE By R A Warren Equipment USA & Fuel Cell Propulsion Institute USA.
e. Electrical Power Output 5 kW, By Fraunhafer Institute for Solar Energy, Freiburg, Germany.

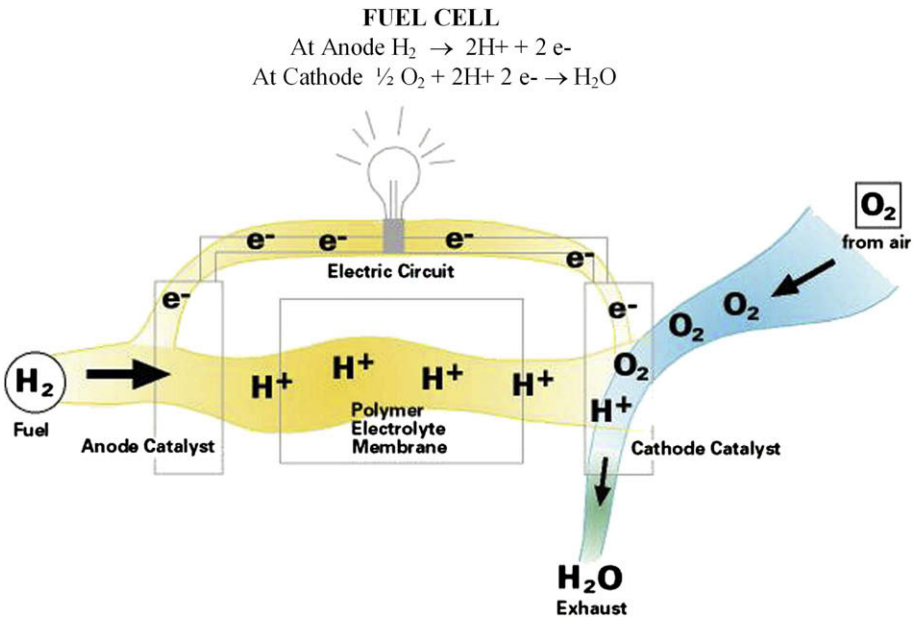

Fig. 11 – Principal of working of fuel cell.

7. Our work & future aspects

During last 20 years our laboratory is working in the field of metal hydrides in thin film and bulk form. Thin film hydrides are important for the applications where one needs small amount of hydrogen. Investigation of FeTi, $LaNi_5$ and misch metal thin film [1–8] have been undertaken for hydrogen absorption, desorption and hydrogen content measurements [5–6]. Similarly a lot of work on bulk hydrides [9–17] studies using FeTi, $LaNi_5$, misch metal, Zr and Mg based alloys has been done.

Seeing the importance of Mg for hydrogen storage for practical applications, work in our laboratory is in progress in this field. Mg nano composites using various transition metal catalysts have been undertaken. We hope to contribute

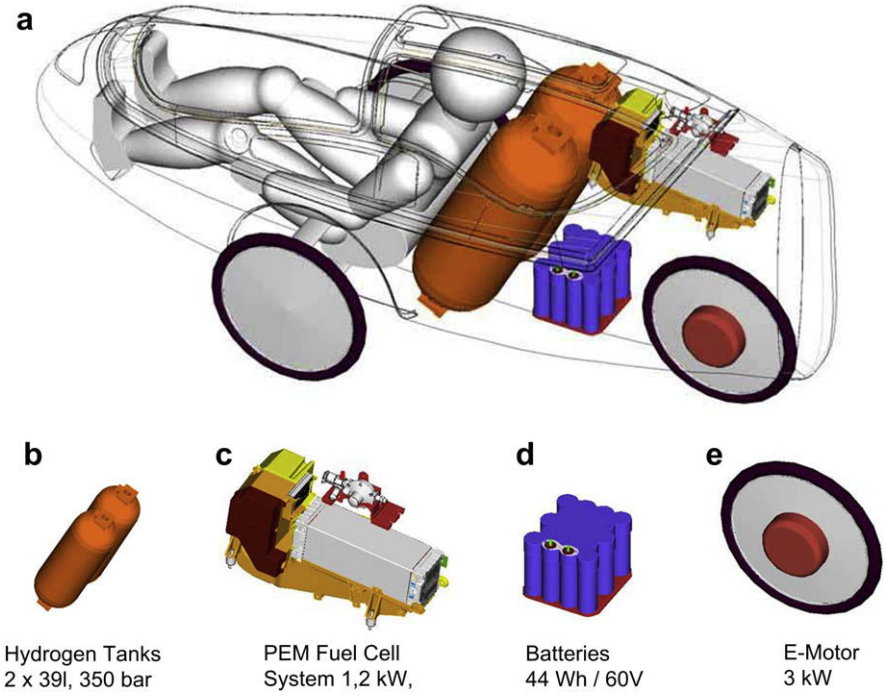

Fig. 12 – (a) Clean, green, silent bike, ENV: emissions neutral vehicle.

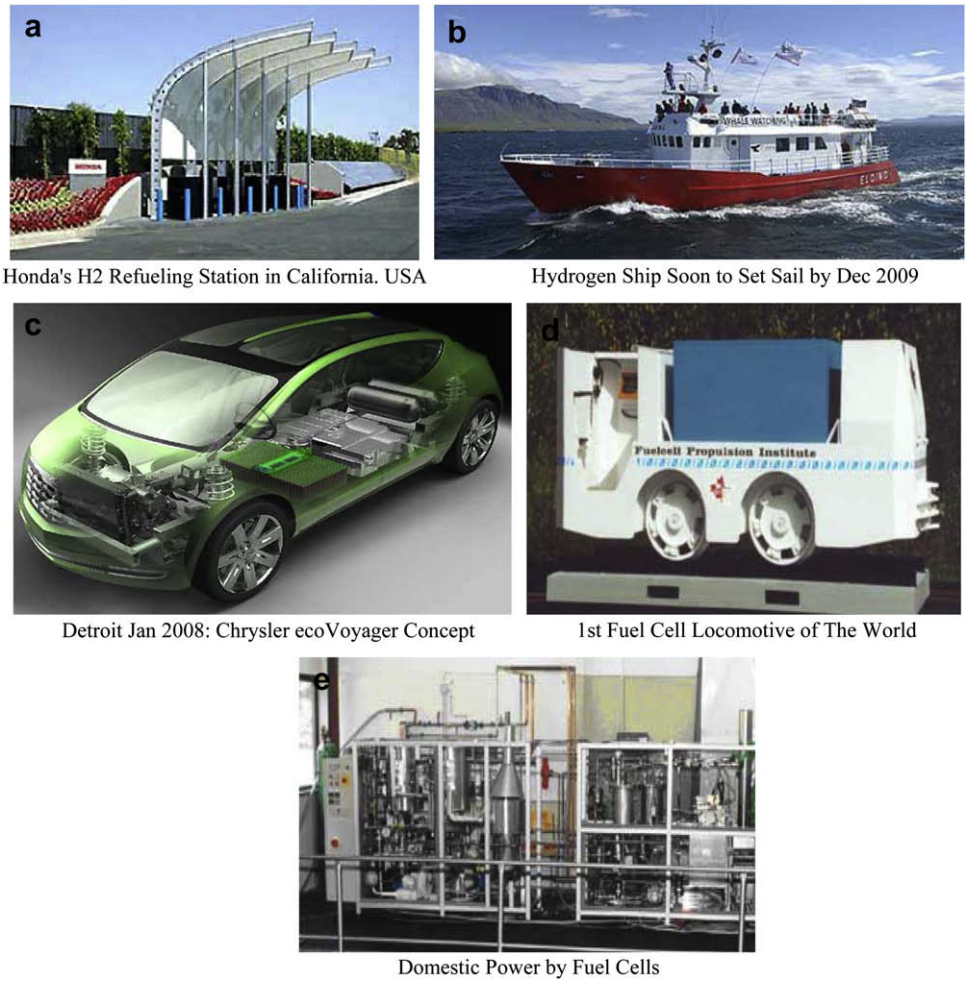

Fig. 13 – (a–e). Some applications of hydrogen energy and fuel cells.

significantly to make Mg to some extent absorbing hydrogen at lower temperatures.

Future is quite challenging for this type of work, where one can come across magnesium composite absorbing hydrogen at room temperature and desorbing at some what higher than RT. Hydrogen energy at that point will be commercially available for any renewable energy applications.

8. Conclusions

Hydrogen is useful for any type of application, industrial, domestic or space shown below:

- Produce Electricity: using fuel cells.
- Cook Food: using hydrogen burner
- Drive Car: Gas, Liquid or metal hydride can provide Hydrogen Gas.
- Run Factories:
- Jet Plane and Space Craft
- Hydrogen Village.
- Personal Use:
  Domestic Power,
  Mobile Phones, Watches,
  Lap Top Computers,
  Calculators, etc

There is immediate need for the scientific community to realize the importance of finding solutions to make hydrogen energy a commercially viable alternative to fossil fuel. These days due to economic meltdown the prices of oil have gone down, but once this trend changes the prices of oil will jump to the originally higher side and it will be difficult for the ordinary person to afford such high prices. Therefore we have a candidate in hydrogen which has the capabilities to replace oil. Economical, Political and environmental people all over the world are already positive for hydrogen and hence we cannot have a second thought.

Hydrogen at present is three times efficient compared to petroleum and four times costly, with increasing oil prices and decreasing hydrogen production cost, the day is not far when hydrogen will take over oil. The only condition is we have to create an infrastructure for filling hydrogen in automobiles and some safety aspects for its applications for stationary and mobile applications.

In short hydrogen shows the solution and also allows the progressive and non-traumatic transition of today's energy sources, towards feasible safe reliable and completely sustainable energy chains. There are sufficient environmental and public health benefits of direct hydrogen fuel to justify moving ahead based on what we know already about fossil fuels, their consequences and their limitations.

The coming decade will definitely see greater and greater use of ''Green Power'' so as to ensure less dependence on 'Fossil Fuels' and also in order to prevent environmental degradation.

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